Technical Memorandum

Interim Report on Cold Brook Natural Nitrogen Attenuation Project

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Re: Interim Report on Cold Brook Natural Nitrogen Attenuation Project, Harwich, MA

Date: January 29, 2015

Overview/Introduction

Cold Brook is located in southern Harwich. The Brook begins at Grass Pond, flows under Banks Street, through a cranberry bog system that is owned by the Harwich Conservation Trust (HCT), under Hoyt Road, under Route 28, and into Saquatucket Harbor (Figure 1). Saquatucket Harbor is an estuary exchanging tidal waters with Nantucket Sound.

In 2001, the Commonwealth and the towns of southeastern Massachusetts began the Massachusetts Estuaries Project (MEP) to determine the water quality and ecosystem status of estuaries throughout the region. The MEP was implemented through a team of experts led by the Coastal Systems Program, School of Marine Science and Technology at the University of Massachusetts Dartmouth (CSP/SMAST). The MEP involved extensive characterization of each estuary including delineation of its watershed, monitoring of streamwater inputs, measurement of water quality and tidal constituents, and development of a linked watershed/estuary model that could be used to evaluate management options for those estuaries that were determined to be impaired. MassDEP uses the MEP findings for each estuary to develop water quality targets or TMDLs.[1] TMDLs are required under the federal Clean Water Act for any contaminant that causes public waters to fail to attain state water quality standards. If contaminant levels are

[1] Total Maximum Daily Loads

managed and the TMDL levels are attained, the estuary will be restored and will no longer be impaired.

The MEP assessment report of Saquatucket Harbor was completed in 2010.[2] The MEP team concluded that the Saquatucket Harbor ecosystem was moderately to significantly impaired. The report recommended that restoration of the system could be accomplished by reducing the average total nitrogen concentration at a "sentinel station" within Saquatucket Harbor from 0.65 mg/L to 0.5 mg/L. The report also noted that there are a number of ways to achieve this reduction and the MEP report included a preliminary evaluation of one potential option: enhancing natural nitrogen attenuation within the Bank Street Bogs/Cold Brook prior to discharge to the estuary.

MEP measurements at the outlet of the Cold Brook bogs showed that the overall system was removing 35% of the watershed nitrogen flowing through it. Yet, the MEP measured attenuation in other wetland systems and ponds in the region had attenuation rates of 50% or higher. Increased nitrogen removal within the Bogs would allow the Town to avoid some portion of watershed wastewater sewering that would otherwise be necessary to meet the nitrogen loading reductions required to meet the nitrogen TMDL for Saquatucket Harbor. CSP/SMAST staff discussed this finding with the town and their wastewater consultants, CDM Smith, and it was decided to further evaluate the Cold Brook system for potential opportunities to enhance the natural nitrogen removal.

With this in mind, CSP/SMAST staff completed a combined survey of the MEP data and subsequent characterization of portions of the Cold Brook system. This survey suggested a number of data gaps that needed to be addressed related to the system's nitrogen attenuation rate, including: 1) stream flow, water levels, and nutrient transformations within the different portions of the Cold Brook bog, 2) characterization of the irrigation pond, and 3) a complete elevation survey of the bogs, including the bog channels and the surrounding banks. It was also clear that there was a need for synthesis of all the available information in order to provide a reliable basis for discussion of management options. With these needs in mind, CSP/SMAST and CDM Smith worked together to prepare a two-year scope of work with associated tasks for the town.

The first year of this effort was focused on gathering and reviewing the post-MEP Cold Brook assessments (Task 1) and collecting streamflow, water levels and nutrient transformation within the different portions of the Cold Brook bog throughout a whole year (Task 2A). The second year involved completion of a second summer of water quality data to have some sense of inter-annual variation (Task 2B), characterization and monitoring of the irrigation pond (Task 3), a complete elevation survey of the bog and its channels, volume estimates within the cells, and a habitat assessment (Task 4), and development of a summary management plan, including review of options, nutrient reductions, and public discussion (Task 5).

[2] Howes B., H.E. Ruthven, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2010). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Allen, Wychmere and Saquatucket Harbor Embayment Systems, Harwich, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection, Boston, MA. 191 pp.

The first year of this effort was funded and CSP/SMAST was also asked to prepare a mid-year, interim technical memo of project status in order to assist with planning of future activities. This memo includes the initial review of past Cold Brook assessment activities by various groups, as well as an update on monitoring activities through December 2014.

Task 1: Interim Report on Management and Assessment History: Cold Brook System

In order to provide context for future management of Cold Brook System, it is important to consider past assessments in the area and how historic uses have changed the ecology of the area. Cold Brook is part of the Saquatucket Harbor watershed (Figure 2). Saquatucket Harbor was created in 1968-1969 by dredging a salt marsh surrounding what was known as the Andrews River (Figure 3). This marsh river system appeared to be similar to other wetland-dominated tidal river systems along the Vineyard Sound side of Cape Cod, including Herring River, Swan Pond River, and Red River. Historic maps and photographs show the salt marsh surrounding the Andrews River extending up to Route 28 with Cold Brook entering from the west and Carding Brook flowing in from the east. Historic reports named the easternmost brook Cold Brook, but later references have switched these names and this convention will be used in this report. Remnants of the primary stream channel of the Andrews River can be seen in the wetlands surrounding Saquatucket Harbor.

Cold Brook begins at Grass Pond, exiting through an earthen berm (known as Wheeler Dike[3]). The brook flows through a former cranberry bog that was abandoned during the 1950's, through another earthen berm/dam, and under Bank Street. Between Bank Street and Hoyt Road, there are two cranberry bogs that are connected to the brook: an active 7 acre bog south of Harvest Hollow Road and a 35 acre bog system that ceased cranberry production in the 1990s and is now managed by the Harwich Conservation Trust. The larger bog system includes a number of flow control structures that could be used to isolate water flows in various cells of the bog and an irrigation pond (Figure 4).

Cold Brook is a water of the Commonwealth of Massachusetts. As such, there are regulatory issues associated with any management activities in the Brook or its surrounding wetlands, including exemptions and historic accommodations for cranberry bog agricultural activities. In 1927, a Massachusetts Division of Waterways license (No. 769) was issued to construct and maintain dams and spillways at the Grass Pond berm and at the pond outlet upstream of Bank Street for the purpose of cranberry cultivation.[4] The Wheeler Dike berm has deteriorated and the elevation of boards in the Bank Street dam outlet has been subject of a number of regulatory discussions among the town, owners, and MassDEP and its preceding organization, MassDEQE.[5] The Waterways license is still valid and held jointly by the owner of the active bog and the Harwich Conservation Trust (HCT), which owns the bogs east of Bank Street. Both parties also hold MassDEP Water Management Act Registrations that allow specified annual total and daily average volumes of water for cranberry production. State laws also require that

[3] MassDMF memo from Bradford Chase to HCT and John Sennott. March 15, 2011. Subject: Recommended Water Flow Management Plan for Grass Pond and Cold Brook.

[4] Massachusetts Division of Waterways (No. 769) license was issued to George Weekes in March, 1927

[5] *e.g.*, July 23, 1981 MassDEQE letter to Carver Crowell regarding the outlet board elevation being too high; April 20, 2011 Harwich Conservation Commission letter to MassDEP asking for help with board height compliance.

property owners allow passage for sea-run fish.[6] Any activities within the bogs and along the brook will also be subject to the Massachusetts Wetlands Protection Act (WPA), which generally uses local Conservation Commissions to review activities near wetlands and also exempts many cranberry growing activities.

In 2011, Brad Chase, MassDMF submitted a memo to HCT and the owner of the active bog with a Recommended Water Flow Management Plan for Grass Pond and Cold Brook.[7] The primary purpose of the plan was to "allow compatible water flow use for existing agricultural practices and the annual eel migration." No formal agreement was reached regarding the plan, although it was extensively discussed among all parties. The plan recommendations included the following:

1) no changes in water flow or volume between March 1 and July 31 on either side of Bank Street with exceptions allowed for flooding for common bog practices (e.g., late frost protection, fertilizer and herbicide application, etc.),
2) installation of an eel ramp with a 360 gallon per hour pump upstream of Bank Street at the existing dam between March 1 and July 31 to maintain adequate flow,
3) sufficient October releases at the Bank Street dam to allow silver eels to exit Grass Pond
4) regular communication among HCT, MassDMF and the bog owner about uses of water that will impact flows or eel migration.

The MEP assessment of the Saquatucket Harbor system, including Bank Street Bogs/Cold Brook was completed in 2010.[8] The assessment included delineation of the overall Harbor watershed with subwatersheds for each of the streams, collection of parcel-specific information to develop a watershed nitrogen load, and monitoring of flow and water quality over one hydrologic year. The combined information was used to develop the site-specific attenuation with the Cold Brook subwatershed. This detail was added into the rest of the Saquatucket Harbor assessment to produce a recommended threshold nitrogen concentration, as well as combined watershed/estuary water quality model. This MEP model has been validated against multiple datasets so that it can be reliably used to test nitrogen management strategies and their ability to attain the recommended threshold nitrogen concentration (*e.g.*, a TMDL once it is approved by MassDEP and EPA).

There have been a number of projects in the Cold Brook area that had been conducted mostly following the MEP assessment. The town, CDM Smith, and CSP/SMAST contacted the various land owners and consultants who had conducted studies in the area and also discussed the various management objectives for the Cold Brook system. Post-MEP studies and planning have included the following reports:

2007: Zaremba Environmental Consulting. Ecological Evaluation of the Bank Street Bog Complex. Completed for the Harwich Conservation Trust. 20 pp.

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[6] MGL c. 130, Section 19 administered by MassDMF.

[7] MassDMF memo from Bradford Chase to HCT and John Sennott. March 15, 2011.

[8] Howes B., H.E. Ruthven, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2010). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Allen, Wychmere and Saquatucket Harbor Embayment Systems, Harwich, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection, Boston, MA. 191 pp.

- Primarily characterized plant species found within HCT bog property, but also discussed potential management approaches (relatively passive vs. relatively active)
- Identified two rare plant species (thread-leaf sundew and freshwater cordgrass) and significant number of invasive species
- For the purposes of the survey, the site is divided into 8 areas. 274 species are listed within the overall bog system and within each area are noted in a table. Density/frequency is sometimes described in the area narratives, but not quantified for each area or the overall system.

2010: Haley and Ward, Inc. Cold Brook Fishway Restoration Report. Completed for the Harwich Conservation Trust. 22 pp.

- Completed elevation survey of selected connections ("flumes") between bog cells using "NAD83 datum."[9] Selected spot elevations throughout the system, but not a comprehensive survey of the channels and banks that could be used to determine potential volumes within each bog cell or the streams.
- Collected a single round of streamflow measurements to determine existing flows within the system (information not presented in report). Used these measurements to model stormflows (25 and 100 year storms) and propose designs for replacement and/or removal of existing culverts and water control structures within the bog
- Noted tidal influence within the bog system up to the irrigation pond outlet (site D in Figure 4); not clear if this is salt water or retained freshwater
- Evaluated costs for removing selected flumes at four locations, installing pedestrian walkways and footbridges at four locations, and maintaining road access at one location

2011: Geosyntec Consultants. Cold Brook Tidal Assessment. Completed for Massachusetts Department of Fish and Game, Division of Ecological Restoration. 10 pp.

- Installed 5 water level recorders with 6 minute recording intervals for 29 days between May 12 and June 10, 2011. Recorders were installed in an area generally between the bog and Saquatucket Harbor with a primary focus on the impact on tidal elevations of the dam between Route 28 and Hoyt Road (Figure 5).
- Generally found that tidal movement was relatively unobstructed between gauge locations with truncation of the lower portion of the tidal range caused by higher channel elevations closer to and within the bog (Figure 6). These readings were collected prior to the removal of the dam.
- Tidal recordings in Saquatucket Harbor show a much lower minimum tide (-3.21 ft) than the MEP readings for Saquatucket Harbor (-2.18 ft) (Table 1). The tidal range is similar between the two datasets but the mean elevations are generally between 1.04 and 1.19 ft lower in the Geosyntec readings than the MEP readings. This difference suggests a difference in the benchmark elevation datum that would need to be resolved to complete the comparison of

[9] Needs to be clarified; NAD83 is a horizontal datum, such as latitude and longitude. NAVD29 or NAVD88 would provide a standard vertical (elevation) datum.

the datasets. If the proposed Year 2 RTK/GPS elevation survey is completed, this will resolve this issue.

Table 1. Comparison of MEP and Geosyntec Tidal Elevations in Saquatucket Harbor. All elevations in feet NAVD88. The tidal range is similar between the two datasets but the mean Geosyntec elevations are generally ~ 1.1 ft lower than the MEP elevations, which suggest that the benchmark elevation datum are different in the two datasets and needs to be reviewed/resolved.

measure	Geosyntec H5 station feet NAVD88	MEP Harbor station feet NAVD88	Difference feet
Mean Higher High Water	2.18	3.34	1.16
Mean High Water	1.83	2.87	1.04
Mean Tide Level	-0.14	0.98	1.12
Mean Low Water	-2.11	-0.92	1.19
Mean Lower-Low Water	-2.39	-1.23	1.16
Tidal Maximum	3.18	4.17	0.99
Tidal Minimum	-3.21	-2.18	1.03
Mean Tide Range	3.93	3.79	-0.14

2012: Horsley Witten Group. Sediment characterization including core samples and chemical analysis and a ground penetrating radar (GPR) assessment of sand and peat horizons. Completed for Massachusetts Department of Fish and Game, Division of Ecological Restoration.

- GPR assessment completed by Hager GeoScience, Inc. (HGI) 13 pp. + 4 plates. The four plates show: 1) the GPR tracklines within the HCT bog system, 2) the bottom of the sand layer beneath the bog cranberry plants, 3) the bottom of the peat layer beneath the sand, and 4) the thickness of the peat. Depths of the sand ranged from 1 to 3 ft, while peat thicknesses ranged from 1.5 to >10 ft. The >10 ft thickness is in Cell 2 (Figure 7) and had a depth greater than the radar signal. The series of peat filled basins appears to show that the original stream channel prior to the deposition of the peat was along a path different than the primary channel today.
- Beginning and end points for GPR tracklines had elevation data collected with Sokkia 2700 ISX RTK GPS, which has relative accuracy of less than 0.05 m horizontally and 0.1 m vertically. These elevations were not provided in the plates or report. Depths of sand and peat were calculated by average electromagnetic wave velocities at various radar frequencies and, as such "should be used to provide trends only and not absolute depths." HGI predicted a ±10% depth error with potentially greater error where data separation is greatest.
- GPR signal quality can be confounded by brackish waters and HGI noted that readings in the southernmost portion of the bogs (Cells 7 and 8) had diminished signal quality and are likely more interpretative.
- The soil analysis results (primarily completed by ESS Laboratory, Cranston, RI) focus on lead, pesticides, semi-volatile hydrocarbons, metals, herbicides,

nitrogen, and carbon. Notably, no phosphorus analysis was completed. Samples were collected from both sand and peat layers at 4 sites that matched well installations completed by HW, but details of sampling procedures are not provided. Sieve analysis was also completed on sand samples. No summary interpretation memo is provided.

- Laboratory results detected very low concentrations or trace detections of various pesticides or breakdown products, arsenic, chromium, beryllium, zinc, and lead in both sand and peat, but all concentrations are below the most stringent of MassDEP standards (*i.e.*, soils in drinking water supply areas (S1GW1)).

2013: Massachusetts Department of Fish and Game, Division of Ecological Restoration. Planning process summary. 6 pp.

- Proposed plan for changes to HCT bog system with management goals in each bog cells, including:
  - a) reorientation of existing berms and construction of walking trails and four footbridges,
  - b) reorientation of stream channel and digging of new portions,
  - c) filling and grading of irrigation pond and parts of existing stream channel,
  - d) excavation of sand from large areas of southern bogs,
  - e) removal of large areas of underlying peat in northern bogs,
  - f) modification of the Bank Street culvert,
  - g) removal of dam at south of Hoyt Road.

  Alternatives are also presented for more extensive system changes. No management proposals are offered for Grass Pond or assessment of potential impacts on Saquatucket Harbor or meeting its nitrogen TMDL.

2014: Stantec Consulting Services, Inc. Letter summarizing site visit at Carding Mill Dam on Cold Brook between Hoyt Road and Route 28. Completed for Massachusetts Department of Fish and Game, Division of Ecological Restoration. 5 pp.

- Site visit completed to "observe the dam and adjacent structures to prepare a scope of work for preparation of a reconnaissance level report describing a potential approach for removal of the dam."
- Concluded that "the severely deteriorated condition of the dam necessitates that immediate measures be taken to substantially remove or repair it." Primary concern is that "stone masonry wall along the right side of the outlet conduit is in a state of incipient failure, that this failure will result in a collapse of the overlying cut stone blocks, and that this collapse will likely result in occlusion of the outlet conduit."
- Dam was removed in March 2014.[10]

[10] Before and after pictures are available at: http://harwichconservationtrust.org/cold-brook-dam-removal-project/

Task 2A: Interim Report on Monitoring

In order to assist the town in discussions of completing Tasks 2B, 3, 4, and 5, CSP/SMAST was asked to prepare an interim review of the portion of monitoring data collected during the first few months of year one. Monitoring is on-going, so review and conclusions based on this data should be regarded as tentative and preliminary.

Sampling strategy: As outlined in the scope for the project, CSP/SMAST has been collecting flow and nutrient concentrations at eight (8) locations situated at critical junctures throughout the bog system such that flows and nutrient concentrations can be quantified into and out of specific cells in the former cranberry bog (Figure 8). Through an understanding of the flows and nutrient concentrations associated with individual cells in the overall system, it will be possible to isolate portions of the system that may be more/less suitable for ecological restoration. Two of the eight sampling and flow measurement locations are positioned at the upgradient (Bank Street) and downgradient (Hoyt Street) boundaries of the system in order to capture the overall function of the system as opposed to that of individual cells within the bog network.

Planned sampling is weekly during the warmer months (four events per month, May thru September), every two weeks during temperature transition months (two events per month for October, and April), and once per month during colder temperature months (November thru March) for a total of 27 events. As of the beginning of November, water samples and instantaneous flow measurements and water quality samples had been collected 14 times.

In addition to the sampling at the eight locations, stream gauges were installed at four locations (CB-1, CB-2, CB-5, and CB-8 in Figure 8). These gauges continuously record water levels at the upper inlet to the bog system (CB-1), at the outlet from an active cranberry bog (CB-2), between the main portions of the bog system (CB-5), and at the outlet for discharge from the bog system (CB-8). Measured flow readings at these locations will be used to establish stage/flow relationships to determine accurate average flow conditions.

Gauges were initially installed in early July 2014. During August, a number of the gauges were vandalized and reinstalled. Gauges were programmed to collect water levels every 15 minutes. This data will be validated against the instantaneous readings collected during the regular samplings to produce stage-flow relationships/curves. Given that these types of curves are only valid with a complete year of water flow data, development of these curves will be completed for the final report.

Water quality samples collected at the same time as the instantaneous flow readings were analyzed at the CSP/SMAST Analytical Facility for a variety of nutrient components including: ammonia-N, nitrate/nitrite-N, dissolved organic nitrogen, particulate organic nitrogen, total phosphorus, ortho-phosphorus and particulate organic carbon. Sample collection, storage, and transfer procedures were all completed in accordance with approved[11] quality control and quality assurance procedures. All procedures are the same as those utilized during the MEP for ease of comparison of previous results.

[11] Approved by MassDEP and USEPA

Initial Streamflow Readings: Figure 9 shows the average, maximum, minimum, and 25th and 75th percentile flows based on the initial 14 instantaneous flow readings to date at the eight sampling locations. These flows are corrected for salinity, assuming a 28 ppt incoming salinity, which was the average recorded salinity in Saquatucket Harbor during the MEP data collection period. Among the notable initial flow findings:

a. Flow increases as the brook flows toward the Hoyt Road outlet. Initial comparison of the increases in flow at each monitoring point and bog areas suggest that flows are more strongly influenced by the size of the contributing watershed than simply the associated bog areas.
b. Little or no flow was coming into the system from west of Bank Street (CB-1) or the private bog (CB-2). 10 and 11 of the 14 readings at CB-1 and CB-2, respectively, had no flow recorded. Regional review of historical water levels[12] shows that, on average (Figure 10), water levels and likely associated streamflow will increase as winter progresses. It is unclear at this time how much of a role the flow control structures west of Bank Street are limiting flow. Field observations also noted thicker plant growth in the channels in the upper portions of the bog system; this may also be restricting flow.
c. Flow at the irrigation pond (CB-6) at low tide was always out of the pond to the Brook. This finding suggests that either tidal water is entrained in the pond and/or the pond functions as a groundwater discharge area; further review of water level information may help to clarify this. Instantaneous flow monitoring targeted low tide conditions in order to best measure watershed impacts.
d. Flow out of the system at Hoyt Road (CB-8) over 4 months averaged 25% less than the one year average recorded by MEP. Review of regional groundwater levels shows that water levels during the current monitoring period are ~16% lower than during the MEP measurement period and appear to be the cause of the diminished flow (see Figure 10). These lower water levels also likely play a significant role in the lack of flow at CB-1. Further review of groundwater levels shows that conditions in September to November 2014 were generally near the 10th percentile of readings collected over 50 years, while MEP readings were collected near groundwater level maximums. This variability should be considered in future management discussions.

Initial Water Quality Readings: Figures 11 and 12 shows the average, maximum, minimum, and 25th and 75th percentile total nitrogen and total phosphorus loads, respectively, based on the initial 14 instantaneous flow readings and concentration data collected at the eight sampling locations. Among the notable initial water quality findings:

a. Total nitrogen discharge increased in almost the same proportion as flow as the brook flows toward the Hoyt Road outlet (R^2=0.81). This finding suggests that a similar amount/density of nitrogen is being added to Cold Brook along its length. Delineation of subwatersheds to each of the monitoring stations and assessment of nitrogen loads could be completed to evaluate this further. Total phosphorus readings are somewhat more independent (R^2=0.65), which would be expected because phosphorus is more likely to be attenuated in freshwater environments and is less mobile in groundwater.
b. The daily total nitrogen load between CB-7 and CB-8 was more than half of the measured load at CB-8 (see Figure 11). The daily phosphorus loads at the same stations

[12] Measured in Chatham

was slightly less than half (see Figure 12). This finding suggests that the watershed load (and flow) is being concentrated in the southern portion of the bog/stream system.

c. The average TN load at CB-8 (10.3 kg/d) approximates the annual average TN load measured by MEP (9.9 kg/d). This raises further questions about the lack of flow at CB-1 and whether that influences a watershed change to CB-8 or not. Planned measurement during the rest of the year and a second summer, if funded, may help to clarify these relationships.
d. Review of water quality data showed that in the middle of the system (CB-4, CB-5) most (>90%) of the nitrogen was in dissolved forms, most of the dissolved nitrogen (>80%) was as inorganic nitrogen, and most of the inorganic nitrogen was nitrate/nitrite forms (>90%). This finding suggests watershed inputs of most nitrogen rather than internal system sources since watershed nitrogen would tend to be fully-oxidized nitrate. Most of the DIN downstream of CB-3 is nitrate/nitrite forms (average at all stations >90%). This supports groundwater as an important pathway bringing nitrogen from the watershed to the Brook and is consistent with the linkage between flow and watershed area noted above.
e. The station with the highest average salinity was CB-6 (5.4 ppt). This finding combined with flow observations[13] suggests that flood tides with relatively high salinity reach as high as the irrigation pond. CB-5, which is next closest station upstream, had an average salinity of 0.1 ppt. It also suggests that this higher salinity water becomes "trapped" in the irrigation pond; the next closest downstream station (CB-7) had an average salinity of 2.6 ppt. It is interesting to note that while the irrigation pond may be contributing a small load to the brook, its TN levels are similar to brook levels; the lower load being attributable to lower flows. Further characterization of the pond would help to clarify its role in determining water quality characteristics in the Brook.
f. Average water characteristics coming from the cranberry bog (CB-2) had decidedly different averages than the rest of the system: i) average TP concentration >3X any of the other station averages, ii) average DIN concentration <10X any other averages, iii) particulate carbon concentrations >4X any other averages, iv) particulate organic nitrogen >4X any other averages, and v) nitrogen to phosphorus ratio ~50% of average ratios at any of the other stations. Collectively, these readings showed higher phosphorus export, greater nitrogen retention, and nearly equal sensitivity to nitrogen and phosphorus in the cranberry bog water.

Summary

This technical memo discusses monitoring in Cold Brook through the beginning of November 2014. Monitoring activities have continued since that time and planned activities in the rest of Year 1 will provide a more complete assessment of annual impacts and functions within the Cold Brook system. These activities will include continued collection of instantaneous streamflow measurements and paired water quality samples that will increase in frequency as the temperatures rise throughout the spring and early summer. Activities will also include continuation of continuous monitoring of water levels at the specified locations.

The interim review in this technical memo of a portion of the annual data of Cold Brook have suggested a conceptual model of how the Brook functions with the caveat that these readings

[13] See item c above

only represent four months of a year. These preliminary findings have, however, also raised some additional questions about flow, nutrient movement, and seasonal and annual variations within the system. It is suggested that these findings have reinforced the importance of Year 2 activities, including monitoring and interpretation to provide additional context for all of the data collection. As originally proposed Year 2 activities included:

i) Task 2B: one additional summer of water quality and flow collection: will provide three summers of data from Cold Brook (MEP, Year 1, and Year 2: Task 2B),
ii) Task 3: characterization of the irrigation pond will provide further insight into whether it is acting as a higher salinity storage site within the Cold Brook system, further refine its flow and nutrient interactions with the channel that connects it to the rest of the system, and its potential role in system management (also part of Task 5),
iii) Task 4: bog elevation survey will provide cell and surrounding channel volumes, which is key for management discussions; will also review current plant composition (both on the bog surfaces and in the channels), which is also important for future management discussions, and
iv) Task 5: integration and synthesis of all collected data (both Year 1 and Year 2) and past data (discussed above) into a report discussing management options.

CSP-SMAST staff is available to discuss the preliminary review and findings discussed in this Technical Memorandum.

Figure 1. Cold Brook Locus Map. Blue line indicates the current primary path of Cold Brook from Grass Pond to Saquatucket Harbor. Based on March 2012 aerial from Google Earth.

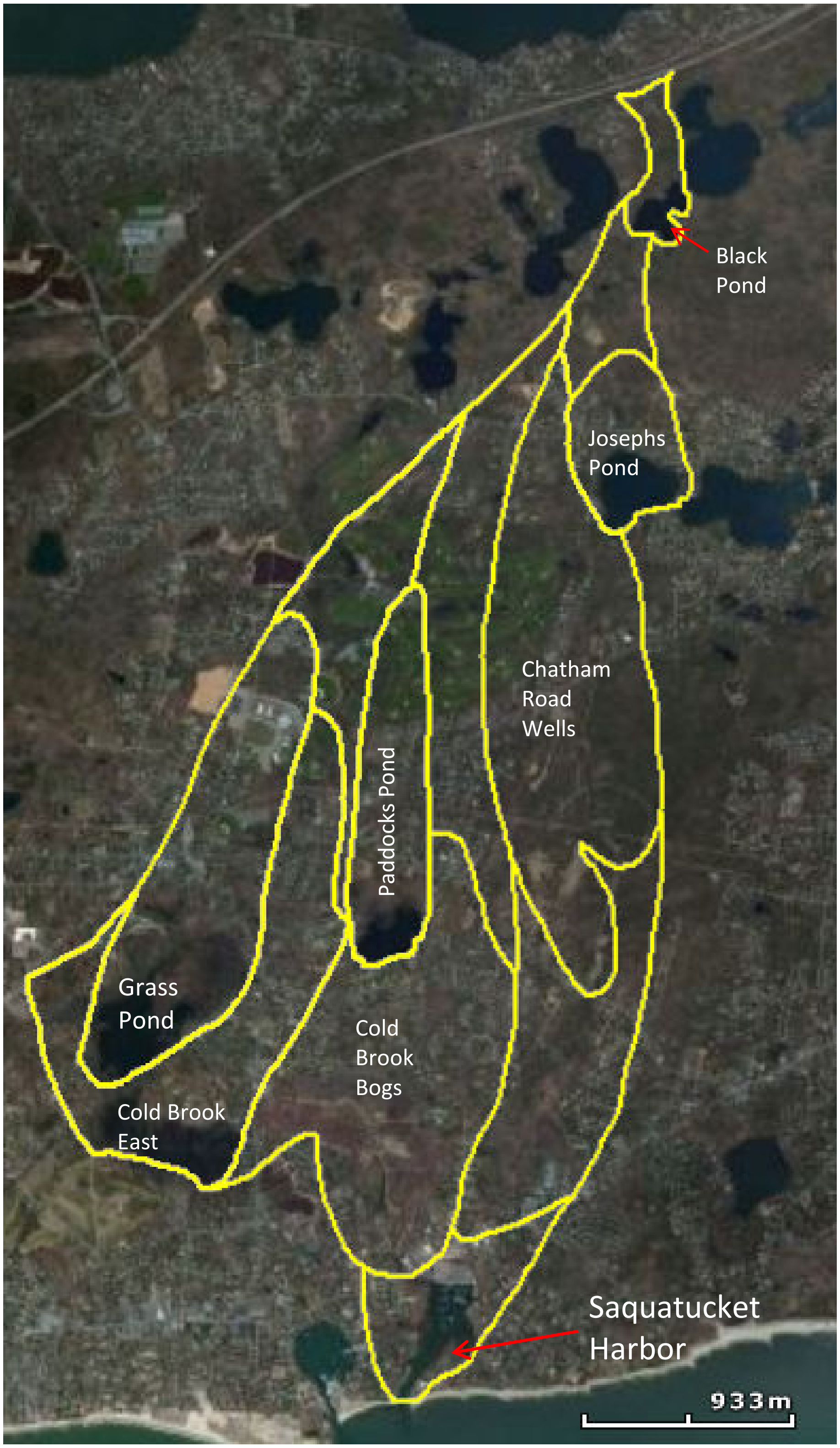

Figure 2. Saquatucket Harbor Watershed. Watershed from 2010 MEP report and shows subwatersheds to ponds, public water supply wells, and streams within the overall Harbor watershed system. Streamflow measurements at Hoyt Road confirm the estimated watershed flow.

Figure 3. 1964 Aerial Photograph of Andrews River Estuary, Harwich. Andrews River was dredged in 1968-1969 to create Saquatucket Harbor. The southern portion of the Cold Brook cranberry bog system is shown in the upper portion of the photo.

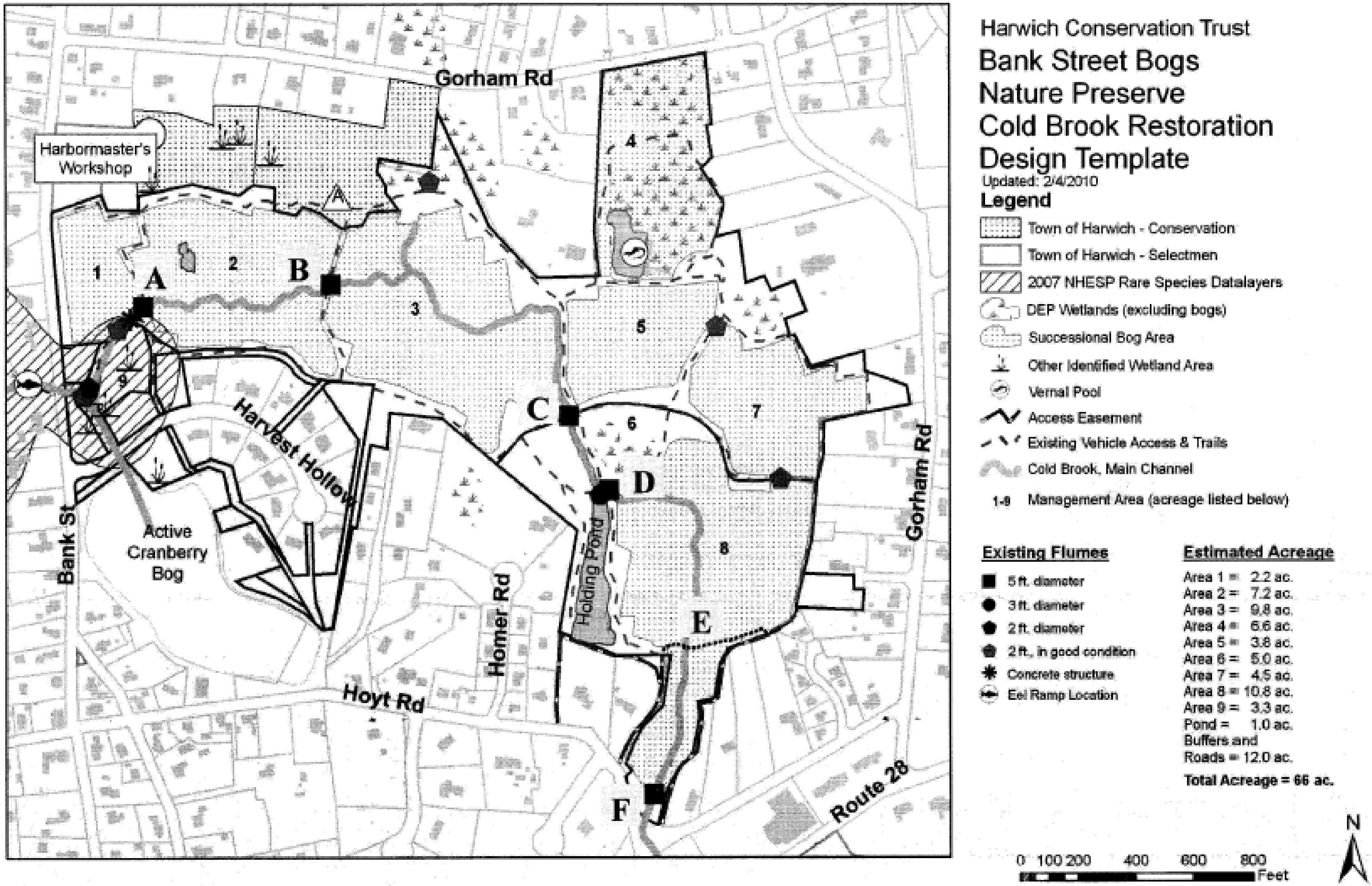

Figure 4. Location of flume control structures with the Cold Brook Bog study area. Structures can be opened or closed to allow water to move between bog cells. Modified from Attachment A in Haley and Ward, Inc. (2010).

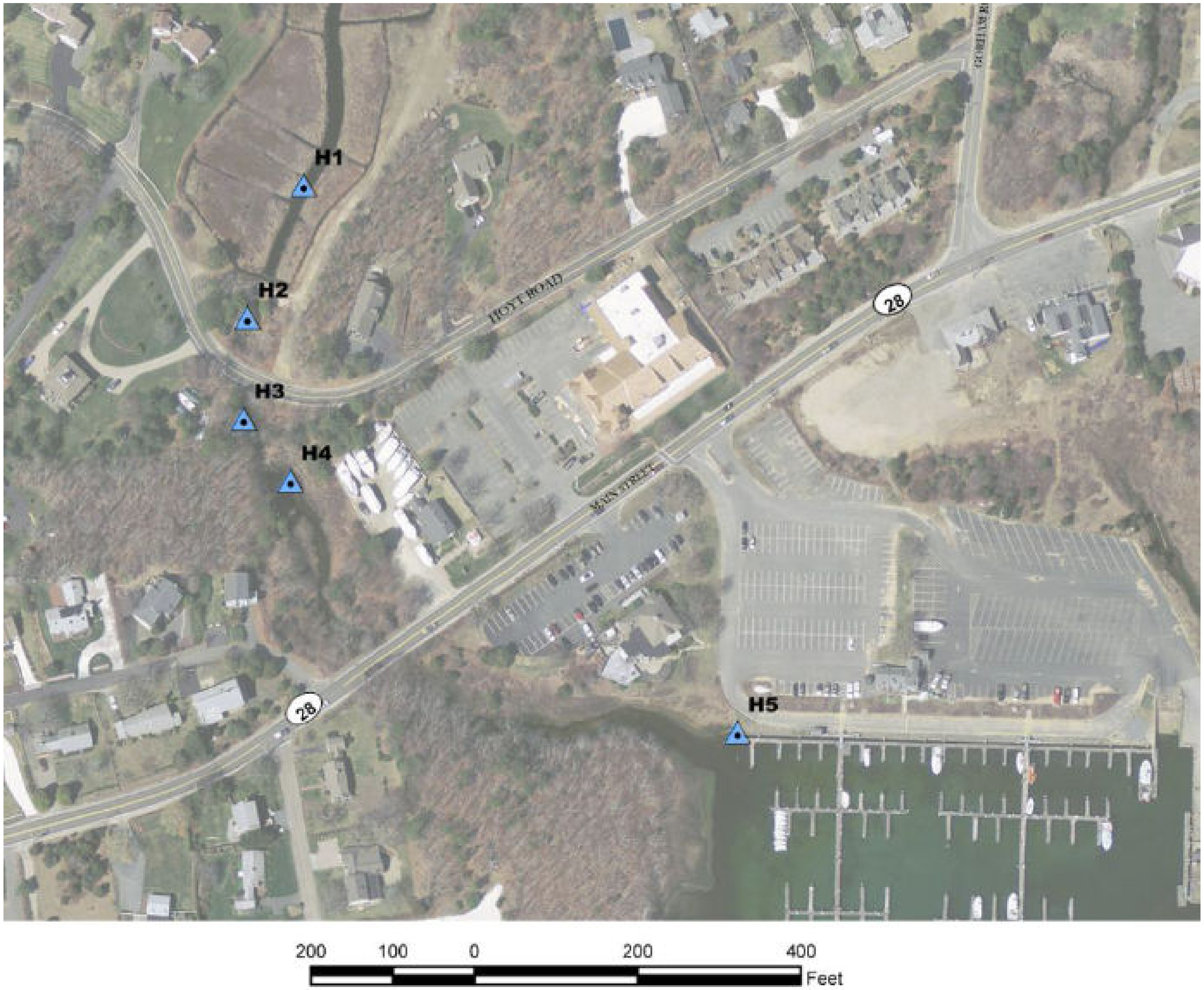

Figure 5. Cold Brook tide gauges locations for Geosyntec Consultants. Gauges were installed and recorded between May 12 and June 10, 2011 using 6 minute recording intervals. Modified from Figure 4 in Geosyntec Consultants (2011).

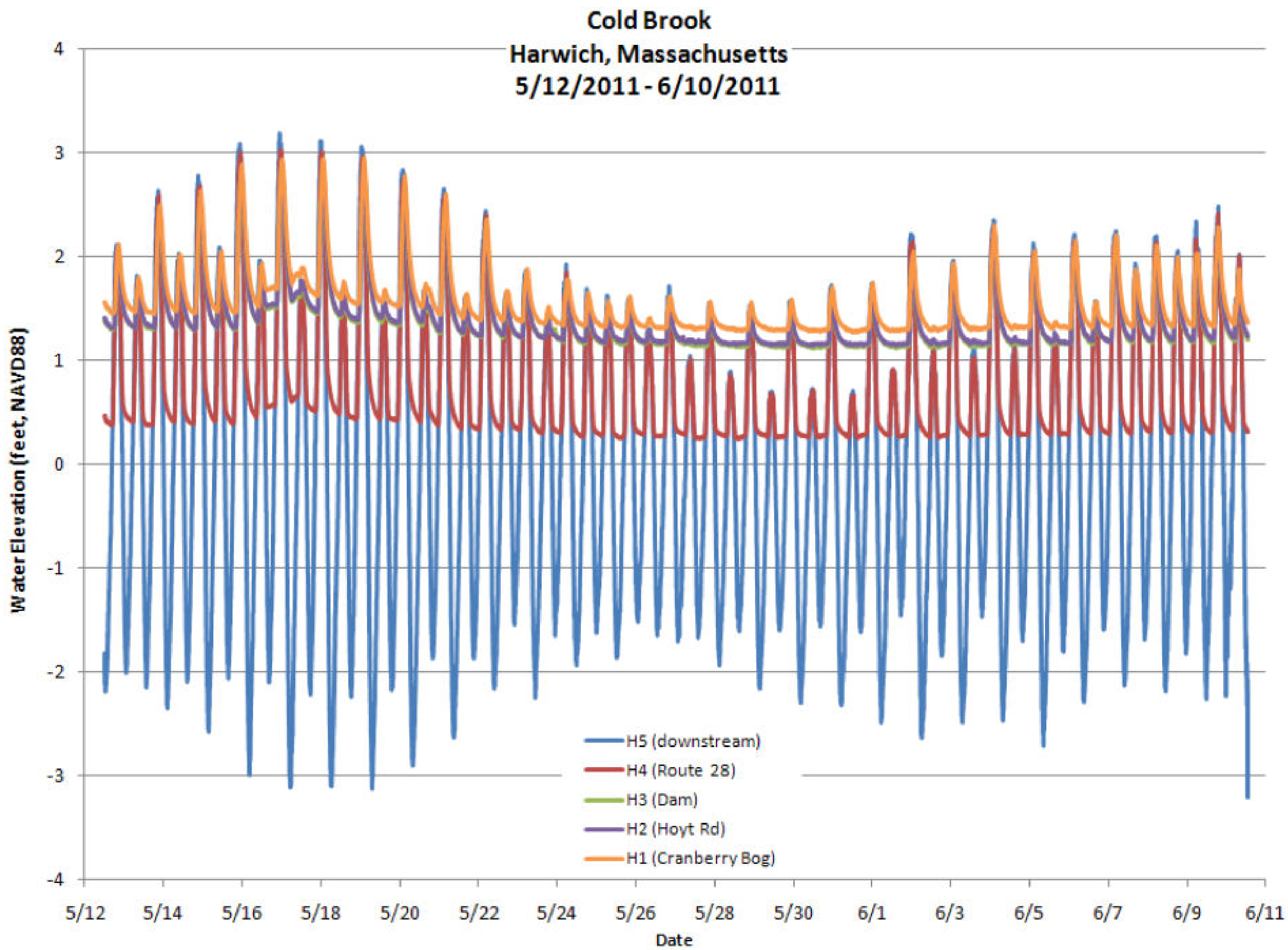

Figure 6. Cold Brook tidal elevation record for Geosyntec Consultants. Generally tidal flow generated roughly equivalent high tide heights throughout the system. Significant truncation of the lower portion of the tidal range is caused by higher channel elevations found closer to and within the bog. This is typical of salt marsh systems where the low tides are higher than adjacent coastal waters. Modified from Figure 1 in Geosyntec Consultants (2011).

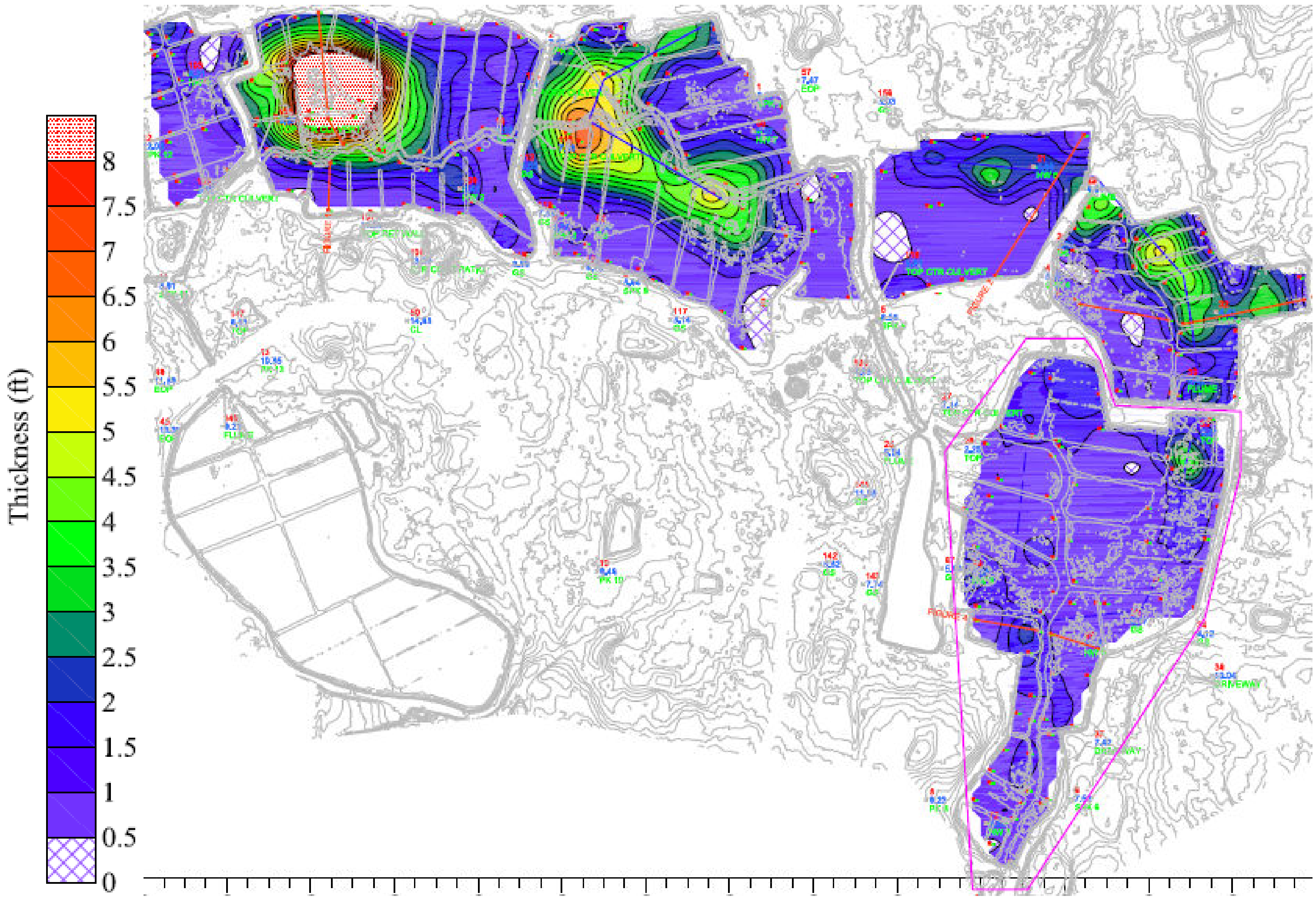

Figure 7. Peat Depth estimated from Ground Penetrating Radar Assessment of Cold Brook Bog. GPR assessment was completed by Hager GeoScience, Inc. (HGI); modification of Plate 4. Peat thicknesses ranged from 1.5 to >10 ft (±10% depth error). The >10 ft thickness exceeded the radar signal and is located in Cell 2 in the northwest portion of the bog system. The series of peat filled basins appear to be residuals of the original stream channel prior to the deposition of peat. HGI also encountered diminished signal quality in the southernmost cells outlined in pink, potentially due to presence of residual salinity from tidal waters.

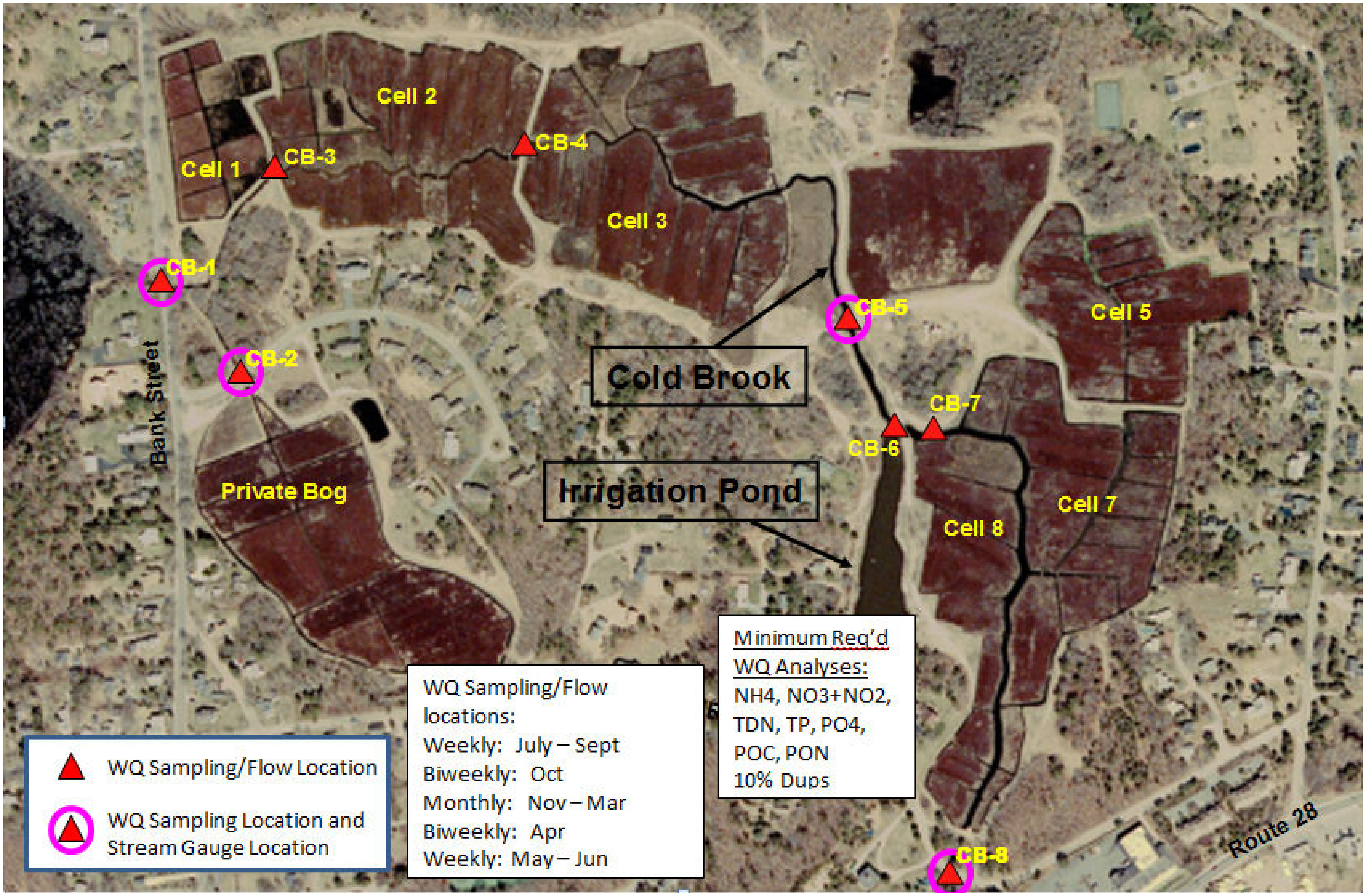

Figure 8. Cold Brook CSP-SMAST Monitoring Stations. Location of the eight (8) monitoring stations for routine instantaneous streamflow recordings and collections of water quality samples are shown. The sampling frequency varies depending on the month/time of year as indicated. Four (4) stations also have recording stream gauges, which collect water levels every 15 minutes.

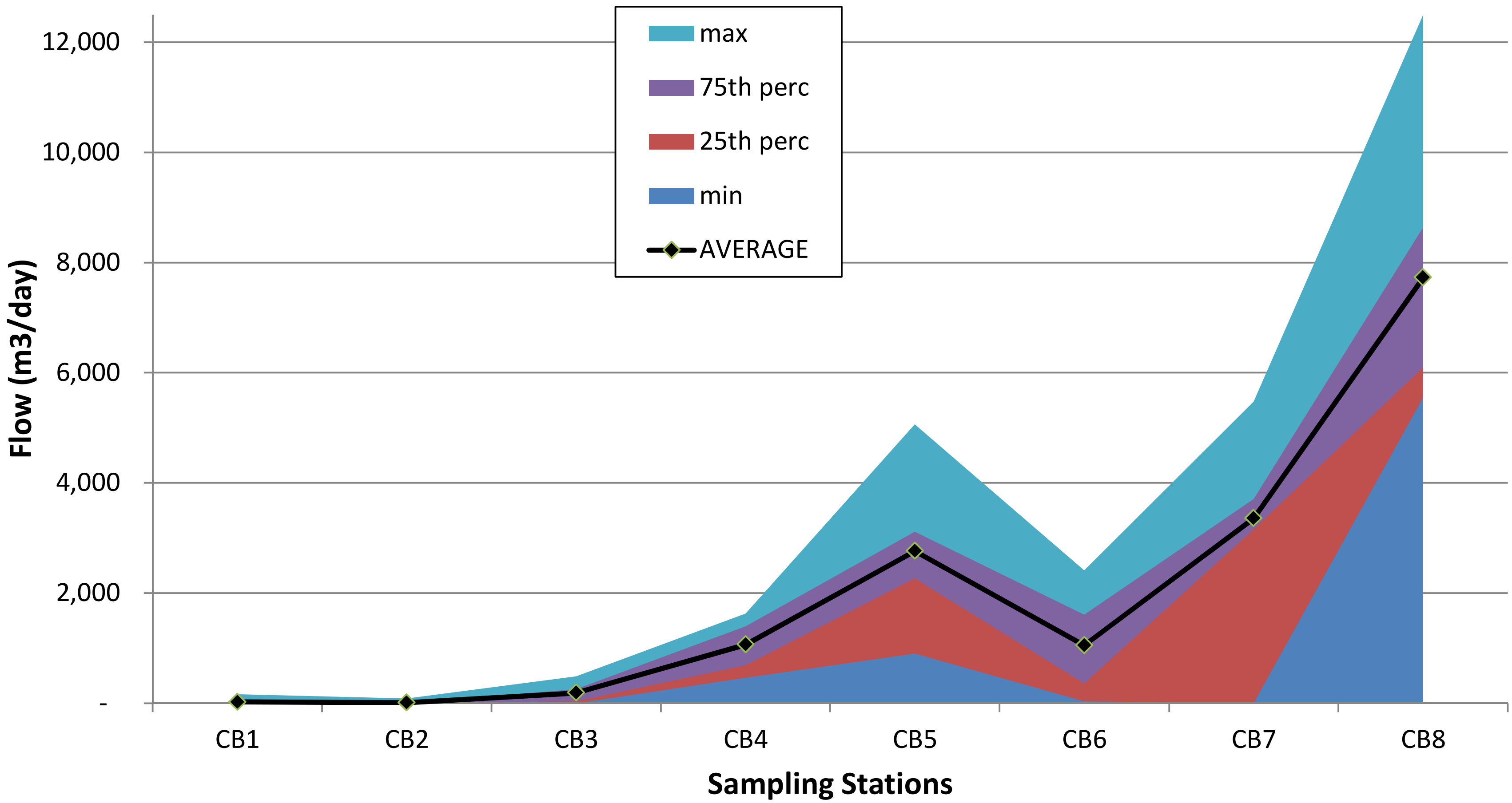

Figure 9. Cold Brook Interim Freshwater Flow Rates. Instantaneous streamflow recordings have been collected 14 of the planned 27 recording dates between July 2014 and June 2015. The graph shows the average, maximum, minimum, and 25th and 75th percentile flows at each of the Cold Brook stations based on the 14 instantaneous readings collected to the beginning of November 2014. All flows have been corrected for salinity; assumed to be 28 ppt, which is the average salinity in Saquatucket Harbor recording during the MEP sampling period.

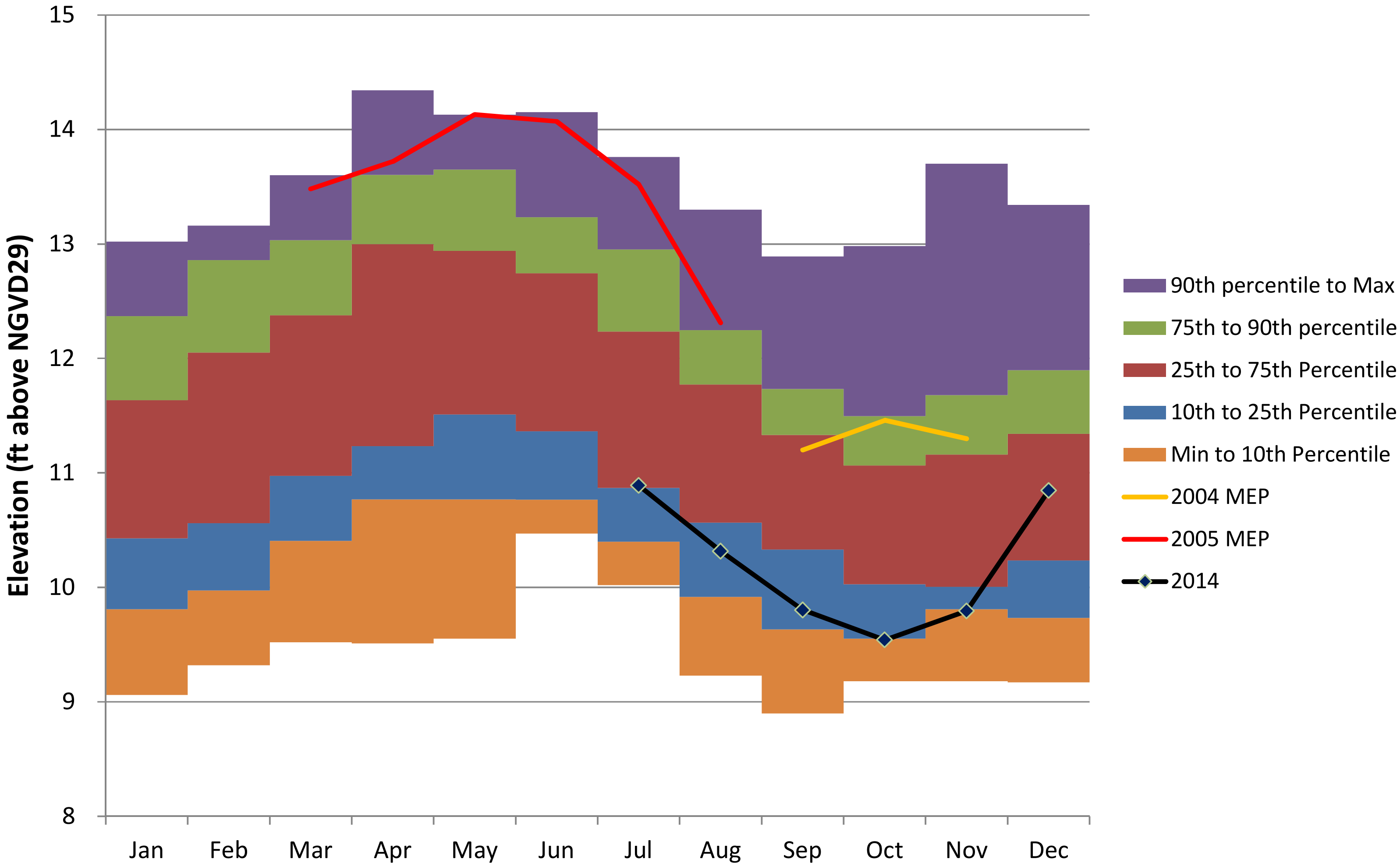

Figure 10. Regional Groundwater Elevations (CGW138). CGW138 is a groundwater well where water levels have been measured mostly monthly for more than 50 years. CSP-SMAST staff developed monthly percentile ranges based on the water levels. The figure also shows monthly readings during the monitoring periods for the 2004-2005 MEP streamflow measurements and the current 2014 interim measurements. Water level readings during 2004-2005 were intermittent, which explains the breaks in the displayed data. It is noteworthy that the 2004-2005 period included some of the maximum historic recorded water levels, while the 2014 period includes water levels at the 10th percentile among past data.

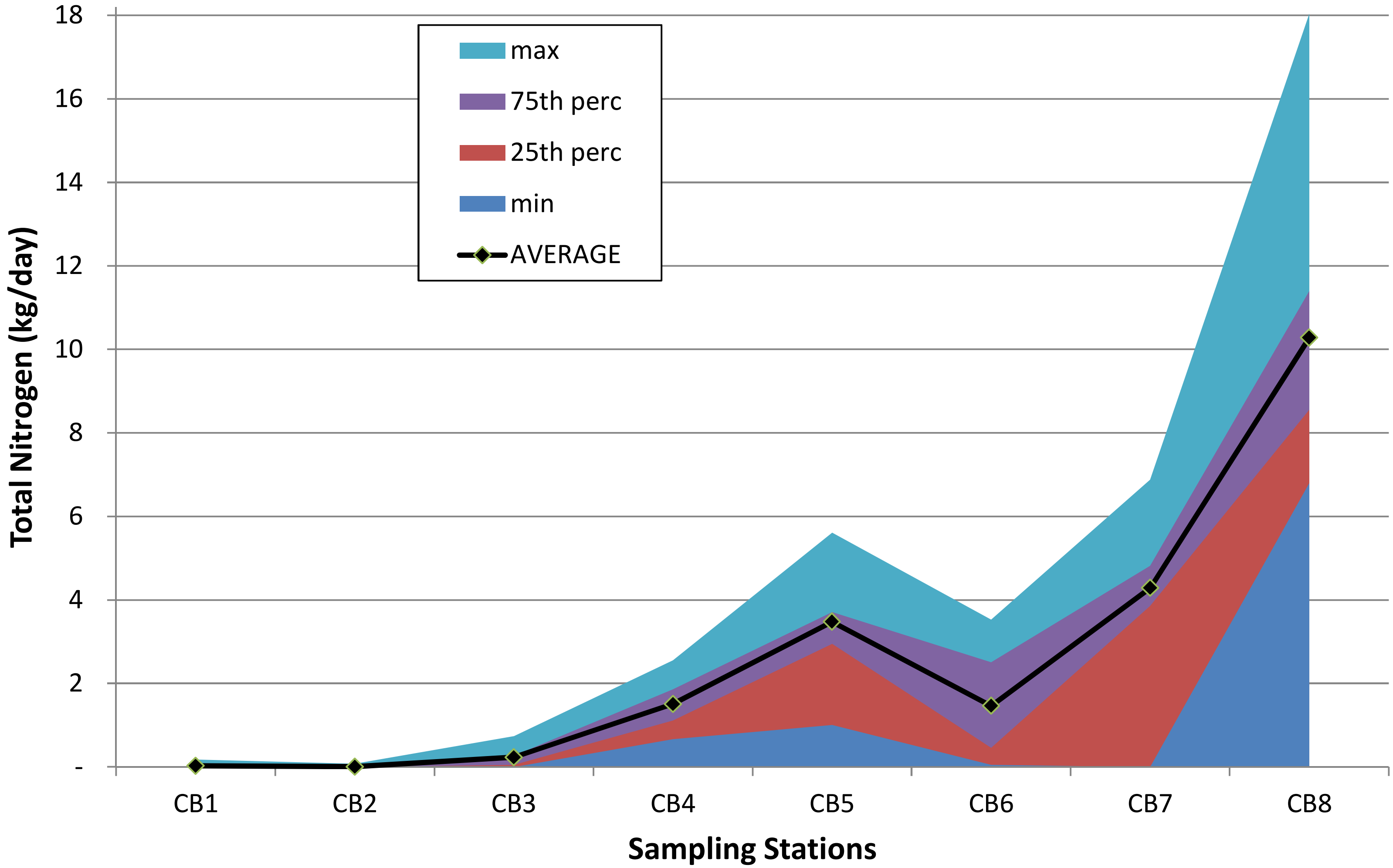

Figure 11. Cold Brook Interim Total Nitrogen Discharge Rates. The graph shows the average, maximum, minimum, and 25th and 75th percentile total nitrogen discharge rates at each of the Cold Brook stations based on the 14 instantaneous readings collected to the beginning of November 2014. Water samples were collected in parallel with the instantaneous streamflow recordings for 14 of the planned 27 recording dates between July 2014 and June 2015. TN rates are based on salinity corrected flows.

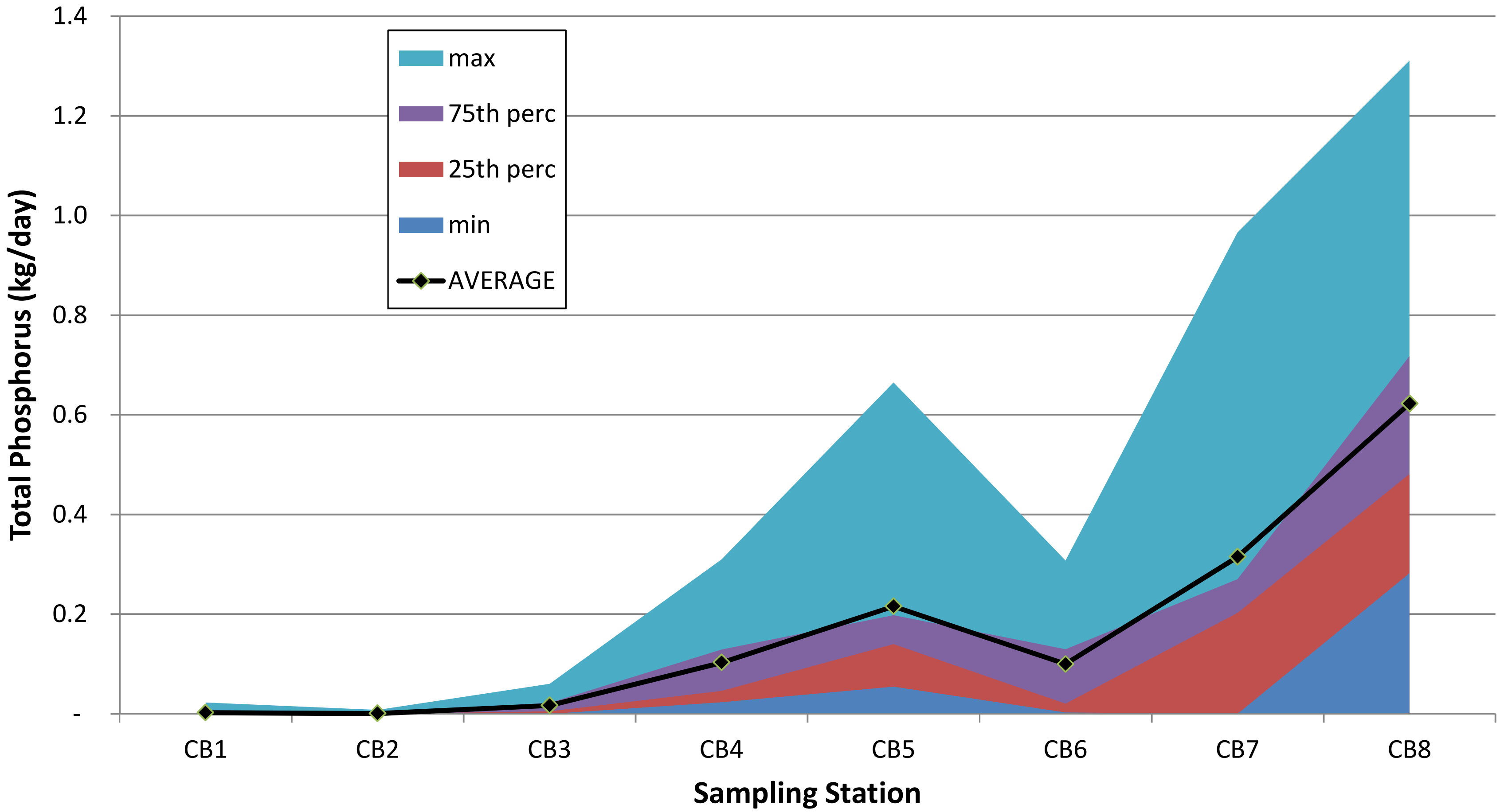

Figure 12. Cold Brook Interim Total Phosphorus Discharge Rates. The graph shows the average, maximum, minimum, and 25th and 75th percentile total phosphorus discharge rates at each of the Cold Brook stations based on the 14 instantaneous readings collected to the beginning of November 2014. Water samples were collected at the same time as instantaneous streamflow recordings for 14 of the planned 27 recording dates between July 2014 and June 2015. TP rates are based on salinity corrected flows